There is clear evidence of the submarine solution of a thickness of about two feet of limestone in the middle region of the Maër Island reef flat between 400–1600 feet from shore; but this may be chiefly due to the carbon dioxide washed outward from the densely forested shores of the Island during the rainy season, and not to the sea water as such.

Indeed the experiments and observations of Dole, and of Vaughan would lead to the conclusion that the sea water of coral reef lagoons lacks free CO_2 and is therefore probably incapable of dissolving limestone.

All species of reef corals survive without apparent injury an immersion for 4 to 5 hours in sea water diluted with an equal volume of rain water, and many species can withstand 11 hours of this treatment, and thus it appears that even torrential rains cannot be an important factor in the destruction of the reef flat corals of Maër Island through dilution of the water, for the tidal range is about seven feet and the incoming sea water would soon offset any dilution due to rains.

The injurious effects of rains upon coral reefs is due solely to the silt which they cause to be washed outward over the flats.

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CHANGES IN SHADE, COLOR AND PATTERN IN FISHES AND THEIR BEARING ON CERTAIN PROBLEMS OF BEHAVIOR AND ADAPTATION

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It is well known that the surface of many organisms is in appearance much like their environment. That is, the organisms simulate their surroundings and consequently are more or less inconspicuous. In some of these organisms the characteristics which produce such simulation are fairly permanent and the creatures correspond in appearance with, what may be termed, the general average of their environment. In others these characteristics may change rather rapidly, in such a way that the animals appear almost continuously like their surroundings, no matter how much they may change. These phenomena have always excited a lively interest in naturalists and a great amount of work has been done on them. They have been particularly prominent in discussions bearing on evolution and consequently most of the investigations concerned questions of function and origin and development, both individual and racial.

This paper however deals primarily with the extent and the accuracy of the process of adjustment to the environment, the factors involved in it, with its bearing on certain associated problems in behavior. Nearly every investigator assumes that the adjustment to the environment in an organism serves to conceal it from other organisms. This assumption rests upon the further assumption that vision in animals is similar to that in man. Thus we have the problem of vision closely associated with the question concerning the function of simulation of the environment. There are also some other associated problems in behavior which are of interest, particularly the one concerning the influence of experience on the rate of adjustment.

1. Extent, accuracy and nature of simulation. Simulation of the environment in fishes involves changes in shade, changes in color and changes in pattern. Nearly all fishes assume a light shade over bright bottoms and a dark shade over dark bottoms, and a considerable number assume the predominating colors of the environment, but in only a few does the pattern change so as to harmonize with that of their surroundings.

In some of the flounders simulation of the background is probably more extensive, accurate, and rapid than in any other animals. Two of these forms, Paralichthys and Ancylopsetta, were thoroughly studied regarding this response. It was found, in brief, that in glass dishes, either on artificial or on natural backgrounds, changes occurred in the skin such as to make the animals very closely resemble the background in shade, color and pattern regardless of great variations in these respects. On a white background they became remarkably nearly white; on gray they became gray of practically the same shade; and on black they became very nearly black. On colored backgrounds varying from dark blue to dark red they assumed colors very similar to those of the background in all but the red. On backgrounds having small figures the figures in the skin became correspondingly small and on those having large figures they became, within certain limits, correspondingly large. There is, however, no indication of an actual reproduction of patterns. While the size of the light and the dark areas in the background and the relative amount of surface covered by them have a profound effect on the pattern produced in the skin, their form and special interrelationship have, within wide limits, no effect.

2. Rate of adaptation to the background. The time required to produce adaptive changes in the skin in Paralichthys and probably also in other genera varies greatly. Under some conditions changes resulting in maximum adjustment have been observed to occur in two minutes

or less, under others it requires several days. In general it is considerably longer for old specimens than for young. It is much longer in individuals kept continuously on a given background than it is in those frequently changed from one kind to another. This is clearly shown by the following: An individual, after having been in a white granite pan continuously for two weeks and long since maximum white, was transferred to a black pan, August 18, 2.05 p.m. At 4.30 p.m. it was about one-half maximum black; August 19, 12 m. about three-fourths maximum black; August 22, 10 a.m. nearly maximum black; August 23, 10 a.m. maximum black. This same individual, after having been frequently transferred from white to black and vice versa, from August 23 to August 30, was taken from the white background where it was maximum white and put into the black pan at 7.27 a.m. One minute later, 7.28, it was already five-sixths maximum black, and after one minute more, 7.29, it was maximum black. The change from black to white however was never observed to be so rapid as this; in all of the experiments it required an hour or more. Thus while it required five days to produce a complete change in the skin from white to black after continuous sojourn of two weeks on white, it required only two minutes after repeated transfers from one to the other.

Changes in color require, in general, much more time than changes in shade or changes in pattern. There is however much variation regarding this among the different colors. Yellow for example, is a color that the fish assume much more readily and rapidly than green or blue. This may be due to the fact that yellow ordinarily predominates in their environment.

3. Factors involved in adjustment to the background. a. Chromatophores: In the skin of the flounders there are colored cells known as chromatophores. Some of these are black and others are yellow of various shades. Associated with these there are other cells which contain numerous highly refractive crystals said to be guanin. These cells are called iridocytes. They appear pure white in reflected light. The pigment in all or in any group of the chromatophores can be concentrated in small globular masses, or it can be spread out so as to cover relatively large surfaces. Moreover, the iridocytes may assume such a position as to hide all or any portion of the pigment in the chromatophores. Thus, changes in shade, color and pattern are produced by reactions in these bodies. And these reactions are regulated by stimuli received through the eyes, as the following experimental observations demonstrate.

b. Eyes: Specimens with the anterior end on white and the posterior

end on black become uniformly maximum white over the entire pigmented surface, with the anterior end on black and the posterior end on white or on a glass plate with intense light reflected through it from below they become uniformly maximum black; with one eye on white and the other on black they assume an intermediate shade (uniform gray) over the entire surface. Specimens, with one eye on a background having a given pattern and the other eye on a background having a different one, assume uniformly over the entire pigmented surface of the body, a pattern intermediate between those assumed when entirely on either background. Careful observation shows that this pattern really consists of a sort of superimposition of a coarser and a finer pattern; for large areas similar to those ordinarily produced when the fish is entirely on the coarser grained of the two backgrounds can still be faintly seen, as well as small areas similar to those ordinarily produced when the fish is entirely on the finer grained background. Thus the configuration in the skin when one eye is on a background having a given pattern and the other on one having a different pattern consists of a superimposition of the configuration produced by each of the two different backgrounds acting alone. The influence of the light received by each of the two eyes is evidently distributed over the entire body and the resulting pattern in the skin is due to a combination of the specific effect of stimuli received from the two eyes.

On a background consisting of any combination of black and white, only black and white is seen in the skin, no color whatever. But if a yellow card is placed within 3 cm. of the anterior end of the fish it becomes strikingly yellow. All of these results indicate that if light has any direct effect on the chromatophores it is insignificant in the process of adjustment to the background. This conclusion is further supported by results obtained with blind specimens.

The removal of either eye interferes but little with the activities of flounders. If the operation is carefully performed the wound heals in a few days and the animals respond normally. They move about and feed apparently with the same degree of freedom as they do with both eyes functional and there is no difference in the extent or the rate of adaptation to the background, neither in color nor in shade nor in pattern.

Specimens with both eyes removed also learn to get around in the aquarium without serious difficulty; but they do not simulate the background, either in shade, color, or pattern.

c. Direction of the light: Specimens on a white background, if they respond at all, become maximum white even if the intensity of the light is so low that they can scarcely be seen and the background appears

dark gray to the human eye. On a gray background, however, even if it appears much lighter than the white in low light intensity, they become gray, on a black, black, etc. If however conditions are so arranged that the eyes receive no light direct from above, that is, receive only light reflected from the background, they become maximum white no matter what the shade or pattern of the background may be. This shows that the changes in shade and pattern and probably also color are in some way dependent upon the relation between the light received directly and that received by reflection from the background.

In accord with this, if the light from above is abnormally strong the fish ought to become dark on a white bottom. Apparatus was devised by means of which such illumination could be produced but it was found that when the light from above was abnormally strong the fish did not respond at all. The significance of this negative result is still somewhat problematic.

d. Comparison of the skin with the bottom: In specimens with the ventral eye removed it was possible to keep the anterior part, with the exception of the eye, so thoroughly covered with sand that the fish could not see any of the skin. Under these conditions adaptation occurred just as accurately and rapidly as it did when the skin could be seen. This shows that the skin is not necessarily compared with the bottom by the fish in the process of adaptation.

4. Selection of background. After flounders have been, for some time, on a given background they tend to return to this background when put onto another near it. That is, they tend to select the background on which they are least conspicuous. This was conclusively proved with reference to shade and fairly definitely with reference to color. The response is, however, of such a nature that, under normal conditions, it is probably of little value in concealing the animals; but it does throw some light on the question of vision referred to later.

5. Biological significance of simulation of the background. Some hold that the phenomenon of simulation is purely accidental and that it has no biological value: others maintain that it functions as a protection from enemies or in capturing prey; a few contend that it serves chiefly to regulate the temperature of the body; and some even hold that it functions in all of these ways and in still others. Unfortunately, however, none of these ideas are supported by experimental evidence. In no case has it ever actually been demonstrated that the response in question has any value whatsoever. This statement includes the results obtained in work on the flounders, although the experiments outlined have as yet been only partially completed.

6. Vision. Since the changes in the skin which result in simulation of the background are controlled by stimuli received through the eyes, the nature and accuracy of the process constitutes an excellent criterion of vision in so far as this term may be used in a purely objective sense.

On the basis of this criterion it was found that, in regard to shade and color, vision in fishes is essentially the same as it is in man; but that in regard to size it is less acute. It was found that flounders distinguish between dots 2 mm. and 3 mm. in diameter respectively, that they recognize dots 1 mm. in diameter but that they do not recognize those 0.5 mm. in diameter.

The most interesting and convincing evidence that we have, however, regarding vision, refers to motion. By means of a background consisting of a rotating disk composed of alternate black and white sectors, it was found that the fusion-rate of images in flounders corresponds very closely with that in human beings. This seems to show conclusively that, in regard to motion, vision in fishes is as acute as it is in man.

There has been so much contention concerning color-vision in animals that it may be well to add a few words in explanation of our evidence bearing on it.

On a background containing only gray or black and white no color is produced in flounders regardless of the shade or pattern or the intensity of the light. Simulation in color is consequently dependent upon the length of the waves of light, not upon difference in its intensity. This is one of the essential characteristics of color-vision in man. We have, however, still further evidence that bears on this matter. Flounders adapted to a given color tend to select a background of the same color: and this selection is of such a nature that it cannot be accounted for on the basis of difference in the intensity of the light reflected by the different colors. It must, therefore, be associated with the length of the waves. Thus the contention that fishes have color-vision is supported both by the reactions of the animals and by the reactions of the chromatophores in the skin. This evidence has, of course, no direct bearing whatever on the problem of color-sensation.

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